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A feasible process tomography and spectroscopy measurement system to determine carbon dioxide absorption

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ABSTRACT

The present study has demonstrated that Electrical Impedance Spectroscopy (EIS) and Electrical Impedance Tomography (EIT) are viable measurement techniques to be used in the measurement and monitoring of carbon dioxide absorption across the scales.

EIS is able to provide information regarding the absorption of carbon dioxide gas on the molecular level hence can be used to search for the optimal system by studying the kinetics of the absorption process and measuring the solubility of carbon dioxide in different solvents of interest.

EIT, however, is more suited to studying the absorption on the macro-scale of the process in terms of aspects such as homogeneity of absorption thus can be used to look at the design of the absorption columns themselves. In the present study the experiments were restricted to studying the absorption of carbon dioxide in water as it was found that the conductivity of industrially relevant solvents such as monoethanolamine was too high for use with the conventional EIT hardware.

1. Introduction

Over the past century global emissions of greenhouse gasses have risen exponentially due to human activities and the ever increasing demand for energy production. Carbon dioxide has been proven to be the single largest contributor to climate change. During the combustion of fossil fuels carbon dioxide is produced and is then released into the atmosphere. In recent years people have become more environmentally literate and increasingly concerned with the effect of carbon dioxide on global warming. It has therefore become evident that there is a need for greener technologies that are capable of meeting the worldwide energy demands without emitting harmful gases. Over the coming years it is expected that there will be a transition to more sustainable fossil fuel technologies and one of the major technologies that is currently being developed to produce energy with low carbon emissions is carbon capture and sequestration (CCS). Large stationary sources of carbon dioxide gas such as fossil fuel fired power plants are the main target for the capture of carbon dioxide capture [11].

Carbon dioxide from the combustion of fossil fuels can be captured and stored in geological formations beneath the earth's surface. At present there are three main technologies being developed for carbon capture, which are described by Hetland and Anantharaman [19] as

(a) **Precombustion**: The CO_2 is separated prior to combustion. The principle behind precombustion carbon capture is that the fuel is turned into syngas in the gas reformer which is a mixture of carbon monoxide (CO) and hydrogen (H_2). The CO then reacts with water to form CO_2 and H_2. The highly concentrated stream of CO_2 is captured and the H_2 can be burned as fuel.
(b) **Oxyfuel process**: Oxygen is used instead of air in the combustion process therefore a flue gas consisting mainly of CO_2 and water is obtained. The CO_2 can then be separated from the flue gas by condensation. As with the post-combustion carbon capture the net electricity output of the power station is reduced due to the energy cost associated with the oxyfuel process.
(c) **Postcombustion**: The CO_2 is separated from the flue gas after the combustion. The principle behind postcombustion carbon capture is that CO_2 is absorbed from the flue gases typically employing the use of amine solvents.

The majority of the research and development currently focuses on the post-combustion technology due to the fact that

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it is already a proven technology and existing power stations can therefore be retrofitted. As previously stated in post-combustion technology the CO_2 produced from the combustion of the fossil fuels is removed from the flue gas of which the major constituent is nitrogen (from air). For a modern pulverised coal or natural gas combined cycle power plant a liquid solvent would typically be employed for the absorption of CO_2. Alkanoamine solvents are commonly used for the scrubbing of acid gases such as CO_2 and hydrogen sulphide (H_2S). The alkanoamine solvents that are of particular commercial interest are monoethanolamine (MEA), diethanolamine (DEA) and methyldiethanolamine (MDEA). Alkanoamine solvents have at least one hydroxyl and one amino group where the hydroxyl group serves to reduce the vapour pressure and increase the water solubility and the amino group provides the alkalinity in water solutions to cause the absorption of acidic gases. Upon the absorption of CO_2 in MEA an ionic solution is produced which would imply that it is electrically conductive. The increase in conductivity of the solution and the drop in pH is caused by the absorption of the carbon dioxide which leads to the ion formation. Therefore, many attentions were made to the dielectric property of carbon dioxide absorption process [17,18].

However the development and implementation of CCS systems is being held back by the lack of measurement and monitoring methods. With this in mind, this paper presents research carried out to investigate the potential of Electrical Impedance Tomography and Spectroscopy in developing a feasible measurement system to be used to monitor the absorption of carbon dioxide.

As a measurement technique for multiphase systems, process tomography has greatly progressed over the last thirty years since its invention in the 1980s. The application of such tomographic techniques has many advantages when compared to other existing techniques; low cost, no radiation hazard and non-intrusive amongst others [7]. Measurement techniques based on tomography are therefore seen as desirable due to the use of non-intrusive or non-invasive sensors located on the periphery of the objects such as pipelines or process vessels [4,16].

At present the main application of electrical tomography within CCS is in the monitoring of CO_2 movements in the geological formations in which they are stored. The Lawrence Livermore National Laboratory is currently involved with research in this particular area and has published several papers on this subject. They have been involved with the CO_2 SINK project Ketzin, Germany, where they have used ERT to monitor the subsurface flow of the supercritical CO_2 within the saline aquifer. ERT has been used as it has the potential to detect resistivity changes caused by CO_2 injection into the saline aquifer [9].

To this end the experimental work in this paper is focussed around two areas of the absorption process which is concerned with a post-combustion capturing system. The first is to investigate the interaction between the liquid and gas interface using Electrical Impedance Spectroscopy which is the equivalent of observing the interaction of the CO_2 and MEA at the surface of the bubble as it travels up an absorption column; thus the experiment will give a great amount of detail into the absorption process through the bubble [1]. The second experiment is carried out using Electrical Impedance Tomography and an absorption bubble column to validate process tomography as a measurement method for the absorption of the carbon dioxide gas into the MEA [10]. The complex impedance distribution images of the absorbed carbon dioxide and the non-conductive carbon dioxide gas are measured and further to be analysed and evaluated for monitoring the absorption process during the dynamic and steady state stages.

2. Experimental work

2.1. Electrical impedance spectroscopy

This section will cover the work which was carried out to investigate the use of Electrical Impedance Spectroscopy (EIS) to observe and measure the absorption of carbon dioxide (CO_2). The experimental work using EIS was based on equipment design for a static absorption system where the EIS could be used to look at the absorption interface between the liquid and the gas.

2.2. Equipment and methodology

From Fig. 1 the design of the equipment can be seen, all three parts where constructed from Perspex so that the experiments could be seen. The base provides the support for the vessel and cap as well as mounting the BNC connectors which allow the equipment to be linked to the Spectroscopy analyser. The vessel section of the design has an internal diameter of 60 mm and mounts four 1 cm^2 electrode plates which are arranged parallel to each other. This is then sealed with the gas chamber cap which has a gas inlet and outlet so that a pure CO_2 atmosphere can be created across the surface of the liquid.

Prior to the acquisition of any data, the experimental setup must be calibrated using a sodium chloride solution which had a conductivity of 1413 mS/cm at 25 °C. The calibration test used an excitation voltage of 1 V and scanned the frequency range from 1 Hz to 10 MHz.

Table 1
Experimental liquids and gases used during experiments.

Liquid	Gas
Water	Nitrogen
Water	Carbon dioxide
30% Monoethanolamine	Carbon dioxide

Fig. 1. Three parts of the spectroscopy equipment design: (a) base, (b) vessel and (c) gas chamber cap.